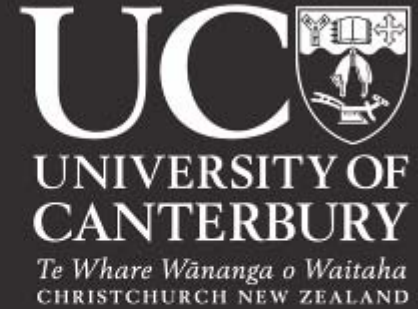


# HUST Biomedical Imaging and Information Research Centre Research Seminar



## Microrobotics for Biomanipulation

XiaoQi Chen (陈小奇), PhD, Assoc Prof  
Director, Mechatronics Engineering  
Email: [xqchen@canterbury.ac.nz](mailto:xqchen@canterbury.ac.nz)

15 December 2008



**New Zealand is located in the South Pacific between the Pacific Ocean and the Tasman Sea, between latitude 35 and 45 degrees south.**



# Liveable Place

- In 1996, Christchurch was acknowledged as the outstanding garden city from 620 international entries.
- In 1997, Christchurch was judged Overall Winner of Major Cities in the Nations in Bloom International Competition to become 'Garden City of the World'!

**“I think every person..... dreams of finding some enchanted place of beautiful mountains and breathtaking coastlines, clear lakes and amazing wildlife. Most people give up on it because they never get to New Zealand”**

**Mr. Bill Clinton – Former US President  
Gala Dinner, Christchurch, NZ 2000**



Dr XiaoQi Chen's Office

Dept of Mech Eng  
University of Canterbury



# Agenda

- [Who are involved?](#)
- [Overview of Mechatronics@UC](#)
- [Microrobotic Cell Injection](#)
- [Force Pattern Characterization of C. elegans](#)
- [Conclusions](#)

# Who are involved


- Supervising Team:
  - Assoc Prof XiaoQi Chen (Director for Mechatronics) - robotics, mechatronic systems
  - Prof J Geoff Chase - dynamics and control, bioengineering, structural
  - Dr Wenhui Wang - robotics, bio-mechatronics
  - Dr Stefanie Gutschmidt - dynamics and vibration
  - Dept of Electrical Engineering, Computer Science, MacDiarmid, HITLab, Bioengineering Centre
- Technical Support
  - Mechatronics and electronics technicians: Rodney Elliot, Julian Murphy, Julian Philips,
  - Mechanical workshop
- Postgraduates
  - James Pinchin, PhD - Low-cost GPS based attitude solution using multiple software based receivers.
  - Patrick Wolm, MEng – Dynamic stability control of front wheel drive wheelchairs.
  - Scott Green, PhD - Human Robot Collaboration Utilising Augmented Reality
  - Ali Ghanbari, PhD – MEMS actuation and precision micromanipulation.
  - Mostafa Nayyerloo, PhD, – Structural health monitoring
  - Chris Hardie, MEng – biologically inspired robots
  - Matthew Keir, PhD – Head motion tracking, graduated in 2008
- Visiting Researchers / Fellows
  - Prof Richard King, Oregon Institute of Technology, Jun 2006 – Mar 2007
  - Prof Clarence de Silva, University of British Colombia, 1-31 August 2008
  - Australian DEST Endeavour Fellowship, Mr Ben Horan, Aug – Dec 2008. Haptics technology
- Interns
  - Julien Dufeu, Institut Francais de Mecanique Avancee (IFMA), 2007. Modelling of wall climbing device
  - Matthias Wagner, the University of Munich, 2007. Design of wall climbing robot.
  - Nikolas Schaal, The University of Stuttgart, 2007. Design of underwater vehicle.
  - Richard Engelaar, Eindhoven University of Technology, 2008. underwater vehicle.
  - Johan Vervoort, Eindhoven University of Technology, 2008. underwater vehicle.
  - Harald Zophoniasson, ENISE, France, 2008. High-precision motorised stage
- Industrial Collaborators
  - Geospatial Research Centre, Dynamic Controls Limited, Industrial Research Limited (IRL), Commtest, etc.

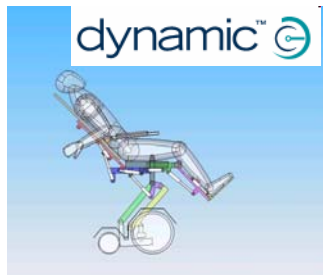
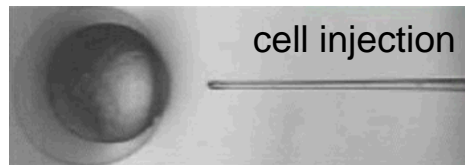


# Mechatronics@UC

## Bio-mechatronics

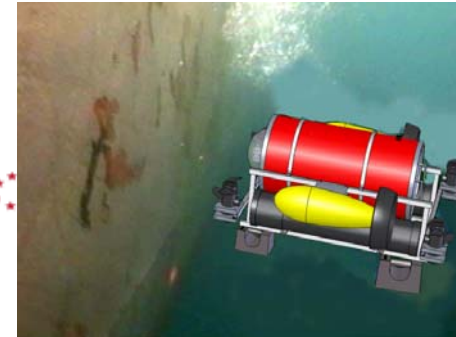
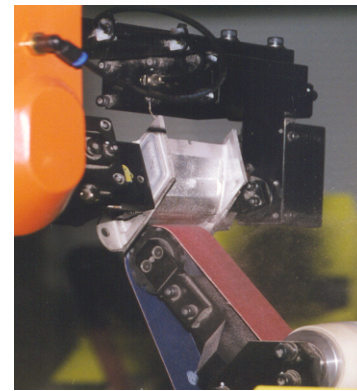
- Assistive devices for rehabilitation
- Bio-micromanipulation – cell injection

 Burwood Academy of Independent Living



## Instrumentation and Automation

- Manufacturing
- Structural control
- Energy harvesting
- Bio-scaffolding



## Mobile Robotics

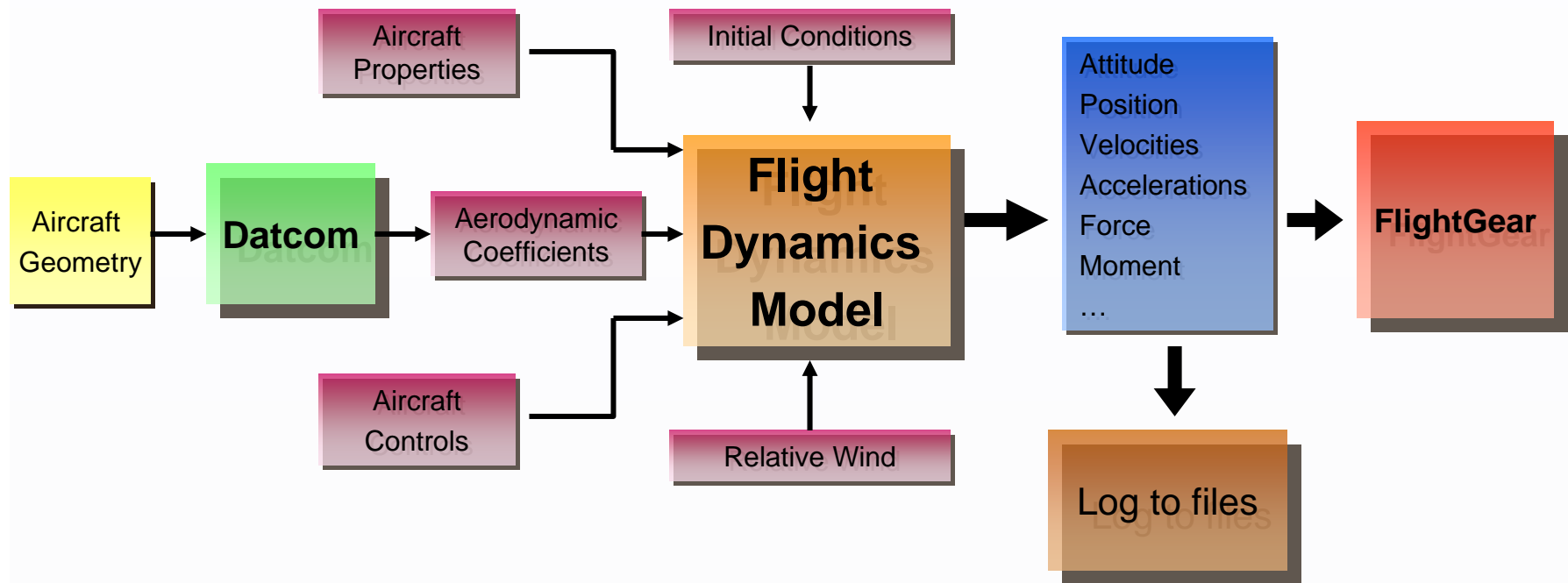
- Unmanned aerial vehicle, micro air vehicle
- Underwater vehicle for bio-security inspection
- Wall-climb robot for tank welding





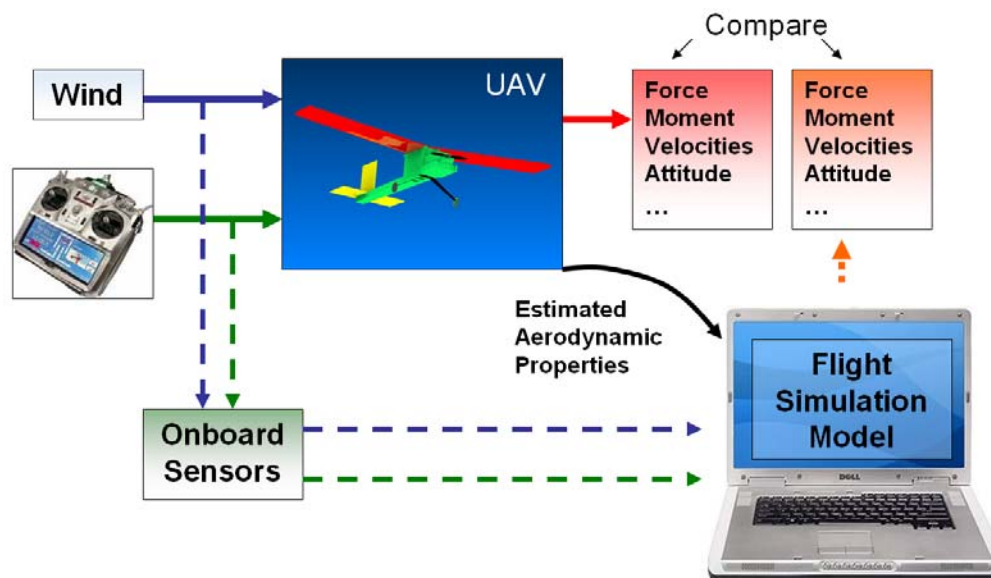
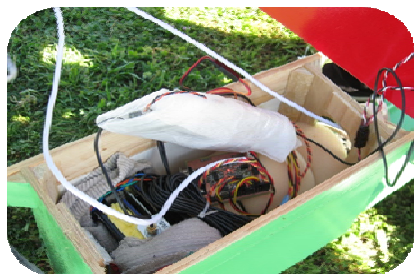
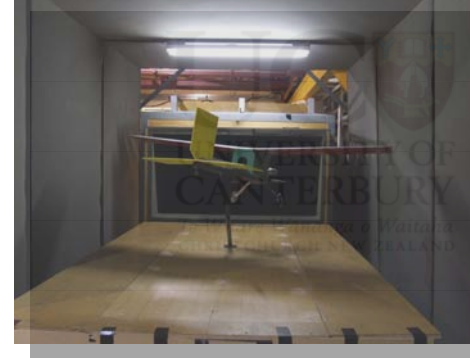
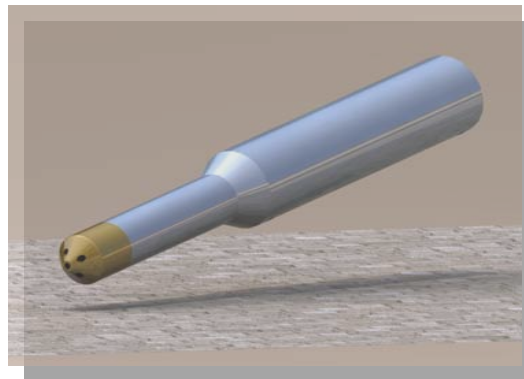
# Integrated Flight Dynamics Model

- The input of aircraft geometry instead of aerodynamic coefficients greatly simplified aircraft model development
  - No wind tunnel testing is required
  - Effects on changing aircraft geometry can be seen immediately
  - Much better repeatability



# FDM Validation with On-Board Instruments

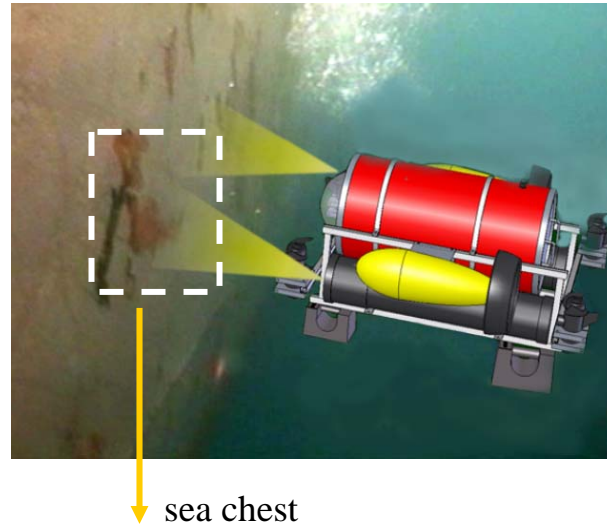
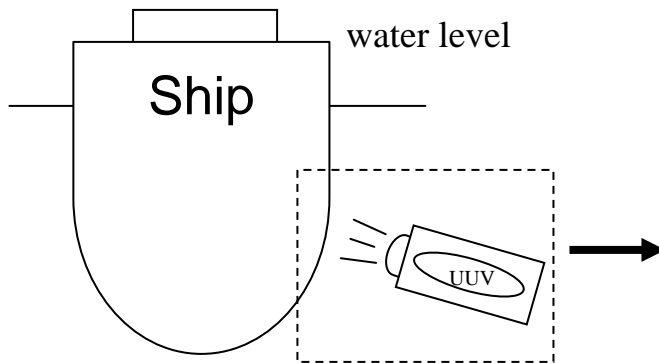
- Equipment used
  - 2.4 meter wing-span gas powered RC plane
  - GPS base station
  - Inertia navigation system
  - Servo pulse acquisition device
  - Wind speed sensor
  - Data logger
  - Wind tunnel



**Video: UAV Test**

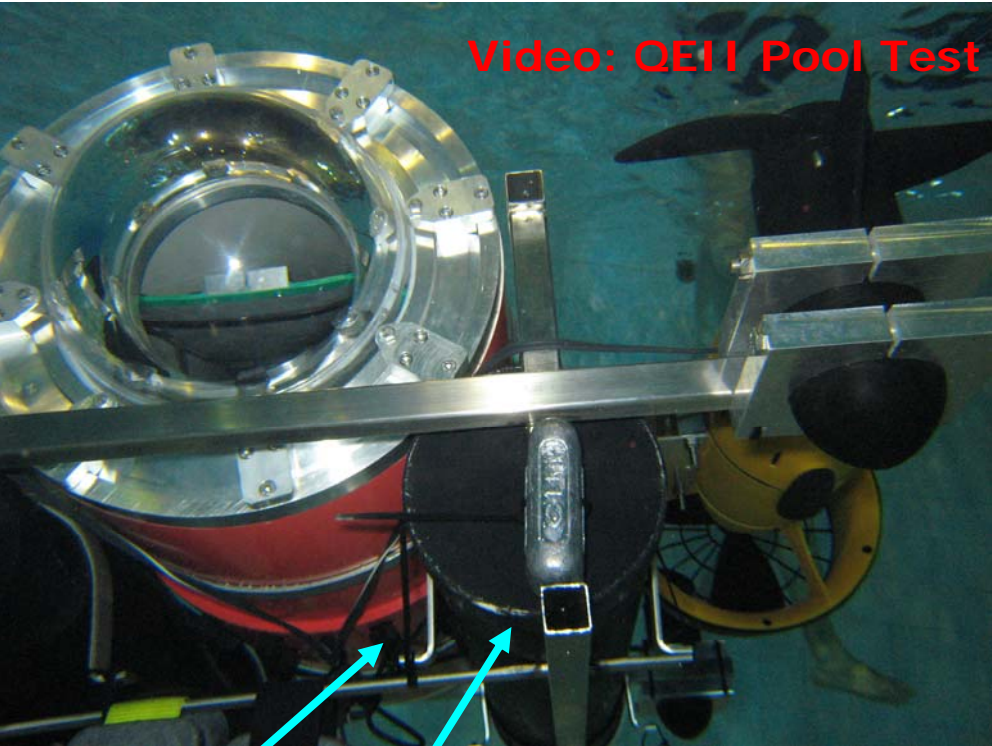
# Canterbury UUV - Biosecurity

For shallow waters, up to 20m depth

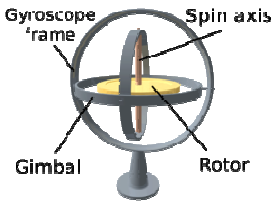




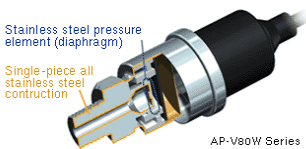
# Vehicle design and electronics



Video: QEII Pool Test



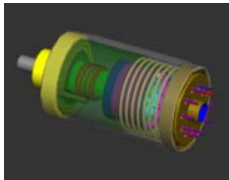
IMU



Pressure sensor-depth



Webcam



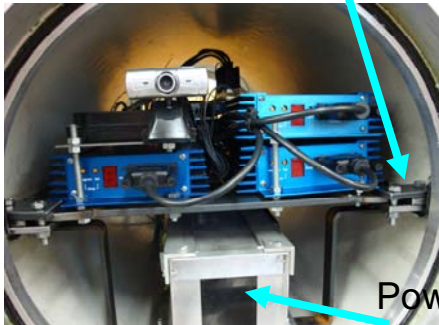
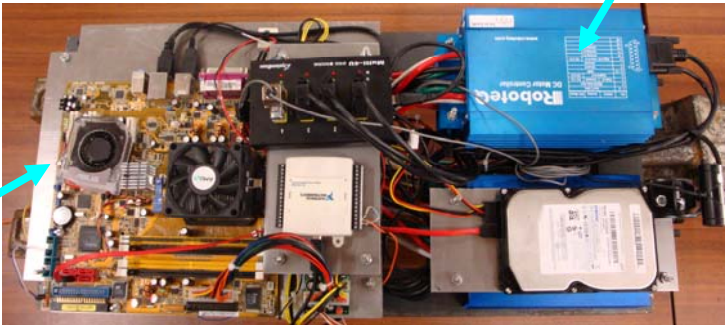
Temperature sensor

RoboteQ motor controller

Sliding mechanism

cable and canister seals

Mother board



Power supply

# UC Wall-Climbing Robot - Performace



The robot is able to transverse the gaps on the wall

High manoeuvrability in every direction, and on different surfaces.

Total weight: 234g

Max attraction force (at 5 bar): 12N



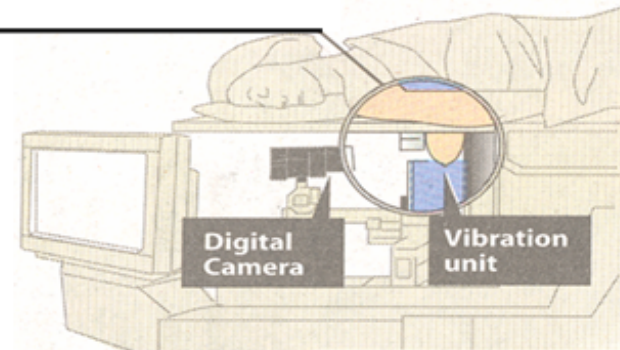
Additional weight that can be lifted (on a wall as on a ceiling): 500g

**Video: Climbing different surfaces and ceiling**

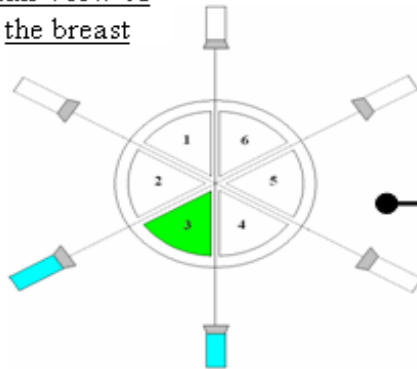
# Digital Image-Based Elasto-Tomography

The DIET system is broken down into 4 fundamental steps: (1) Actuation → (2) Image Capture → (3) Motion Tracking and measurement → (4) Tissue stiffness reconstruction

**1. A woman's breast is vibrated by an actuator and imaged with high-resolution digital cameras.**

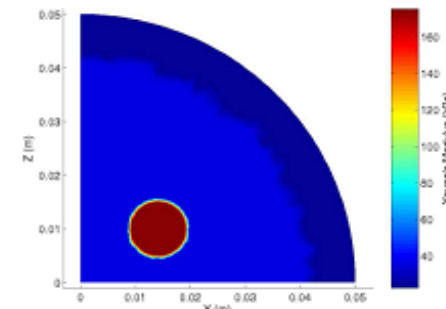
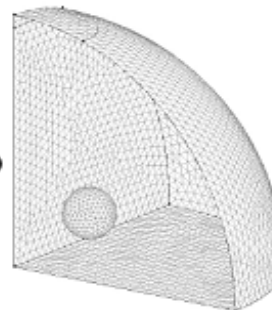


Plan View of the breast



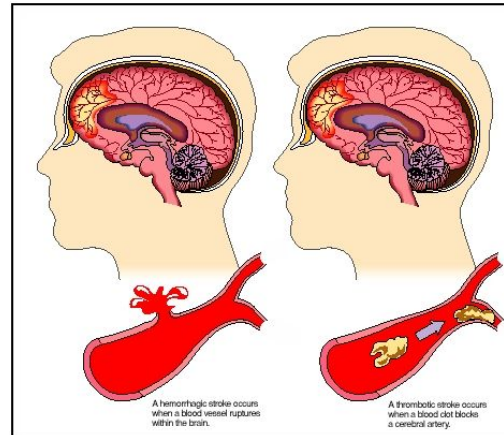
**2. Spatially calibrated digital cameras combined with a motion sensor measures the surface motion of the breast.**

**3. Finite Element method converts the measured breast surface motion into a 3-D stiffness distribution, where regions of high stiffness suggest cancer.**



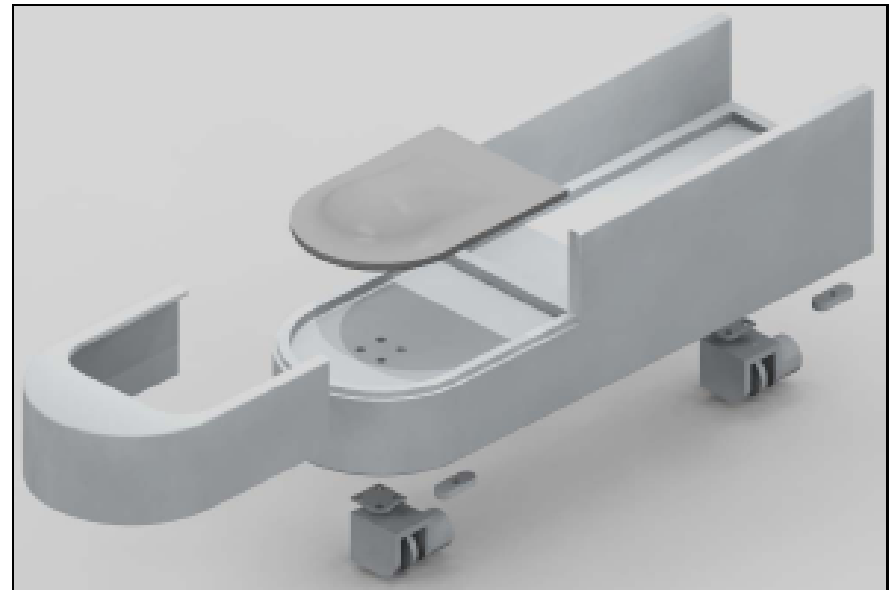


# Variable Resistance Rehabilitation Device



**Video Clip**

**Provisional Patent (2008)**



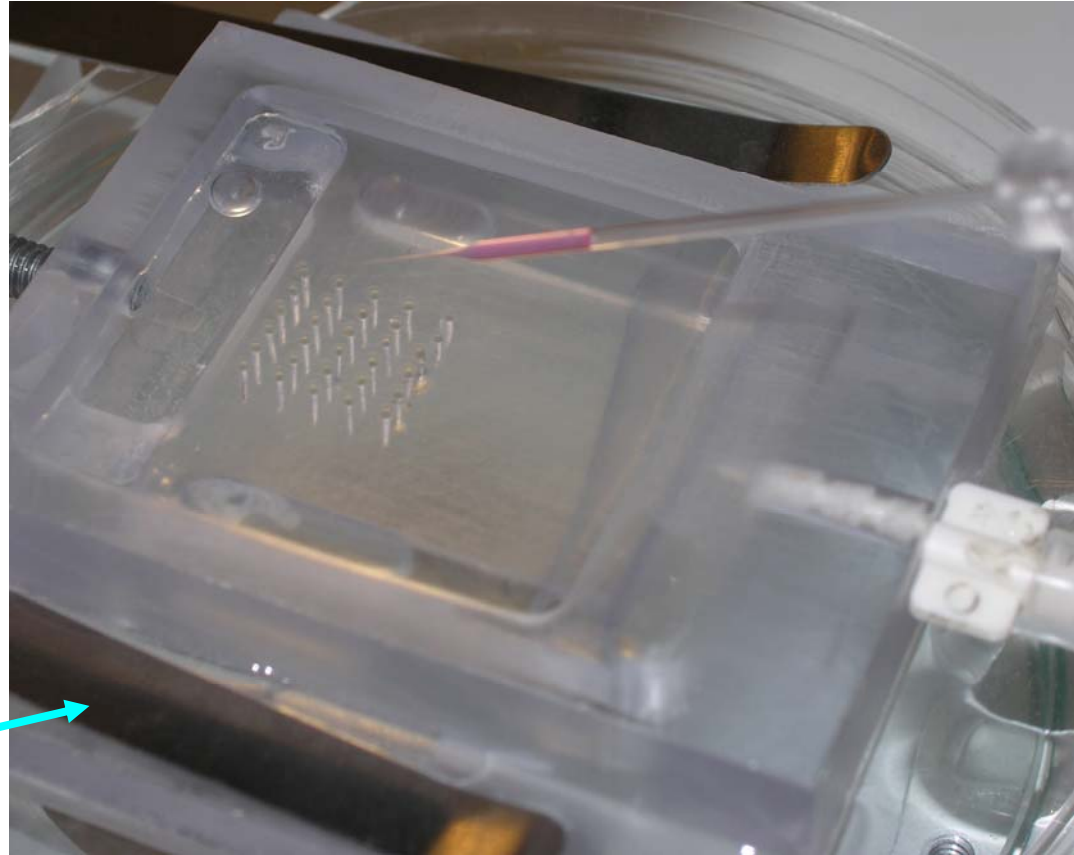
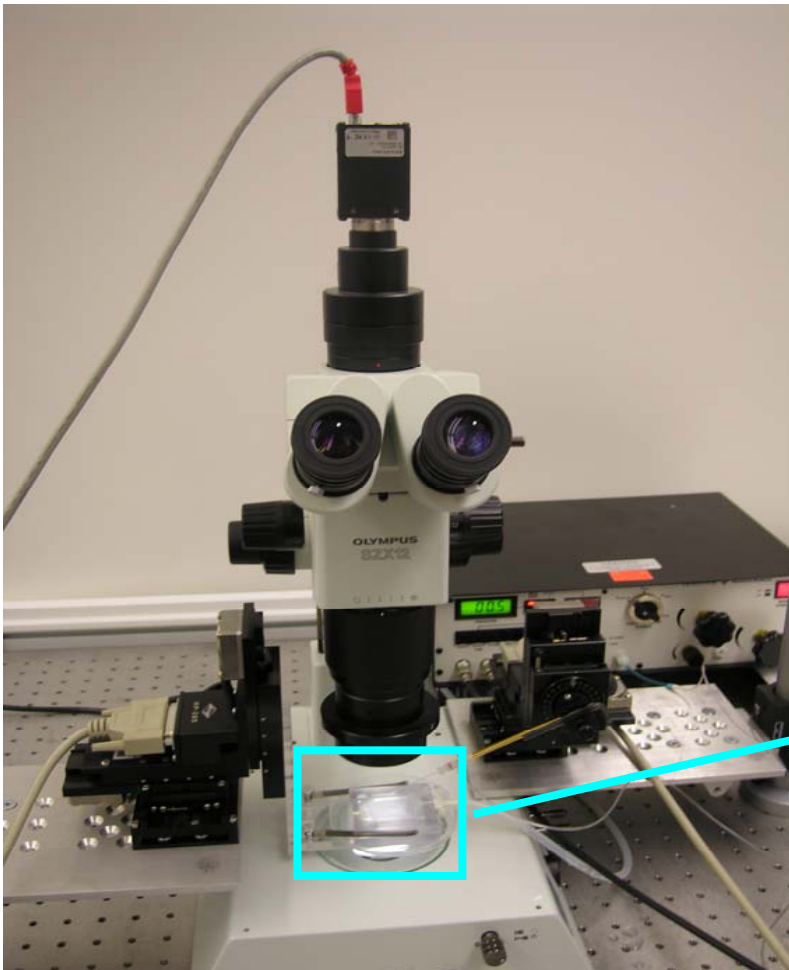
**Back**

# Microrobotic Cell Injection

- Cell Patterning
- Determine 3D information from 2D imaging
- Cell Injection

Wang, WH, Hewett, D, Hann, CE, Chase, JG and Chen, XQ (2008). "Machine vision and Image Processing for Automated Cell Injection," Proc 2008 IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA08), ISBN: 978-1-4244-2368-2, Beijing, China, October 12-15, pp. 309-314.

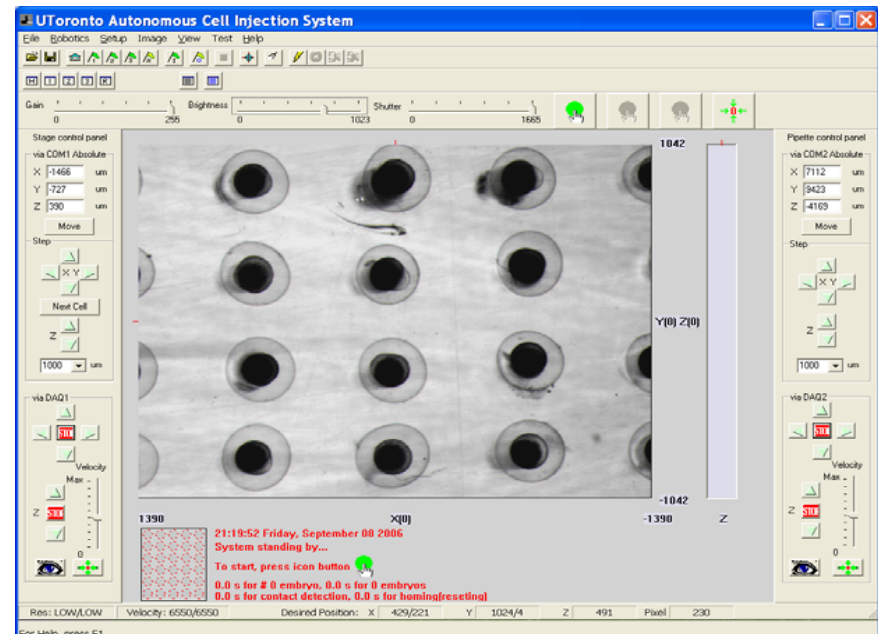
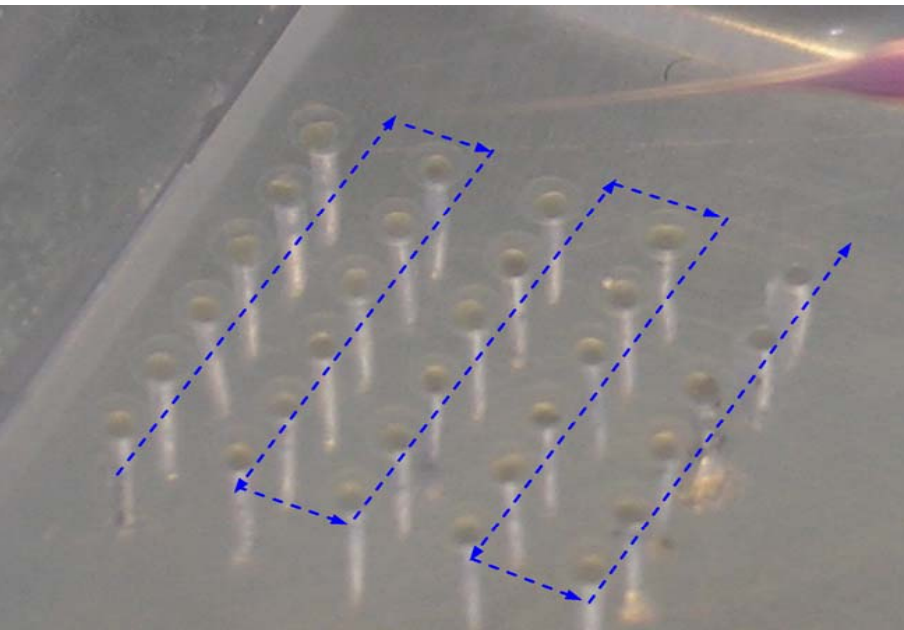
# Microrobotic Cell Injection System



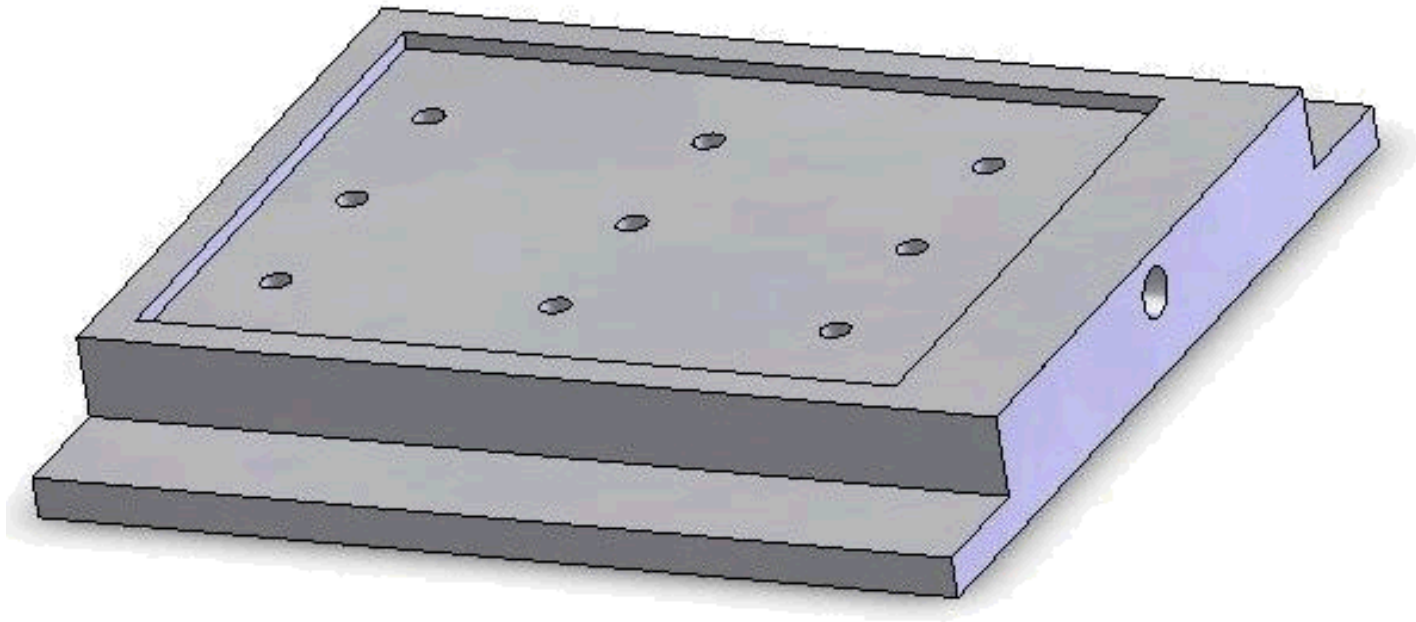


# Challenges to Tackle

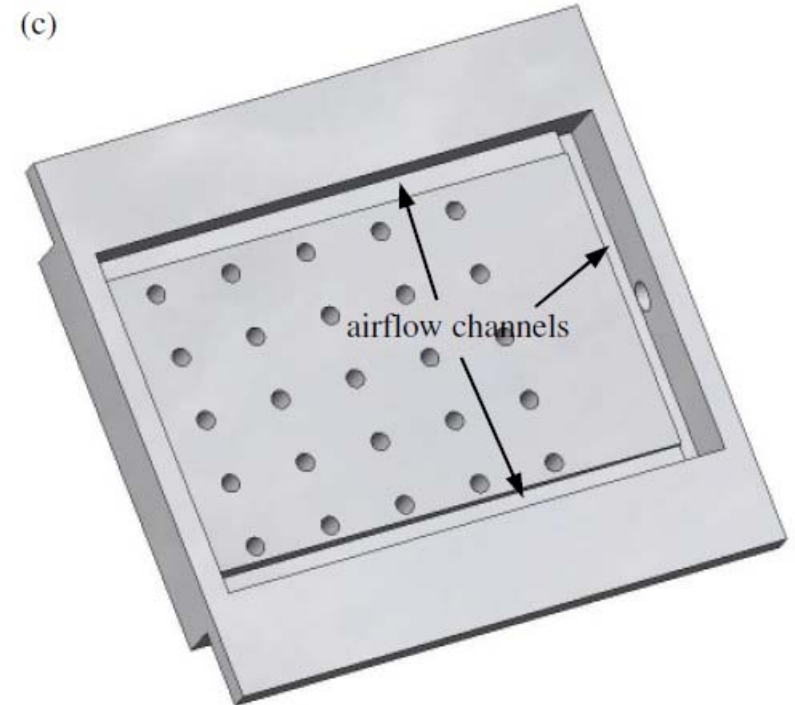
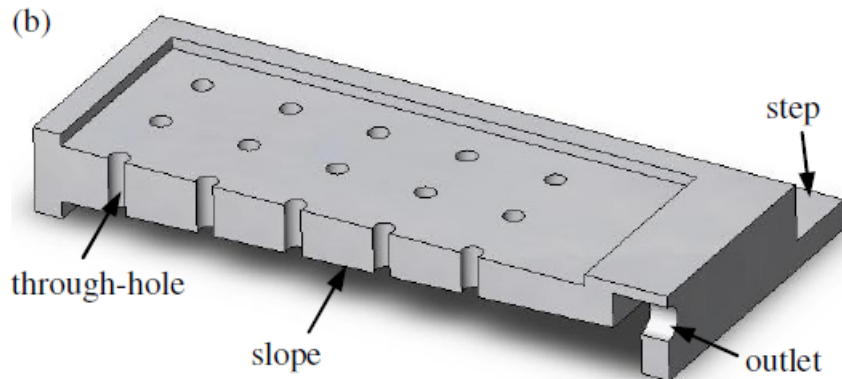
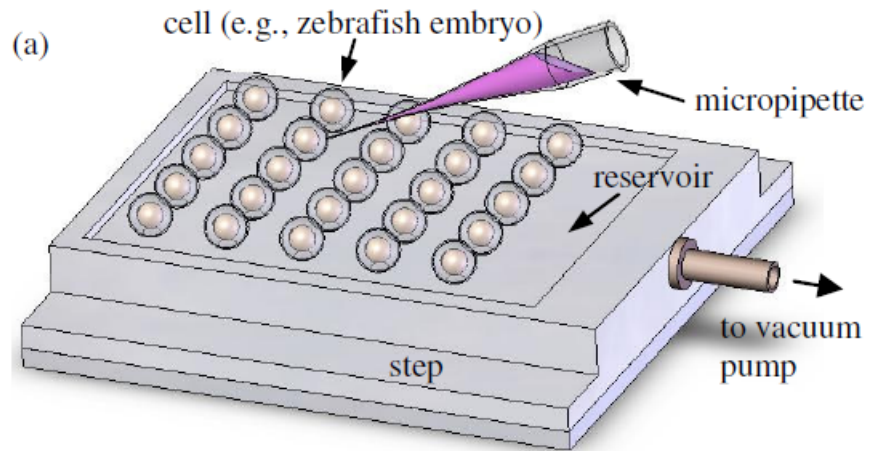
- Immobilize a large number of cells into a regular pattern
- 3D manipulation with 2D microscopy visual feedback
- Robust image processing
- Coordinately control two microrobots
- Optimization of operation parameters to minimize lysis



# Embryo Holding Device

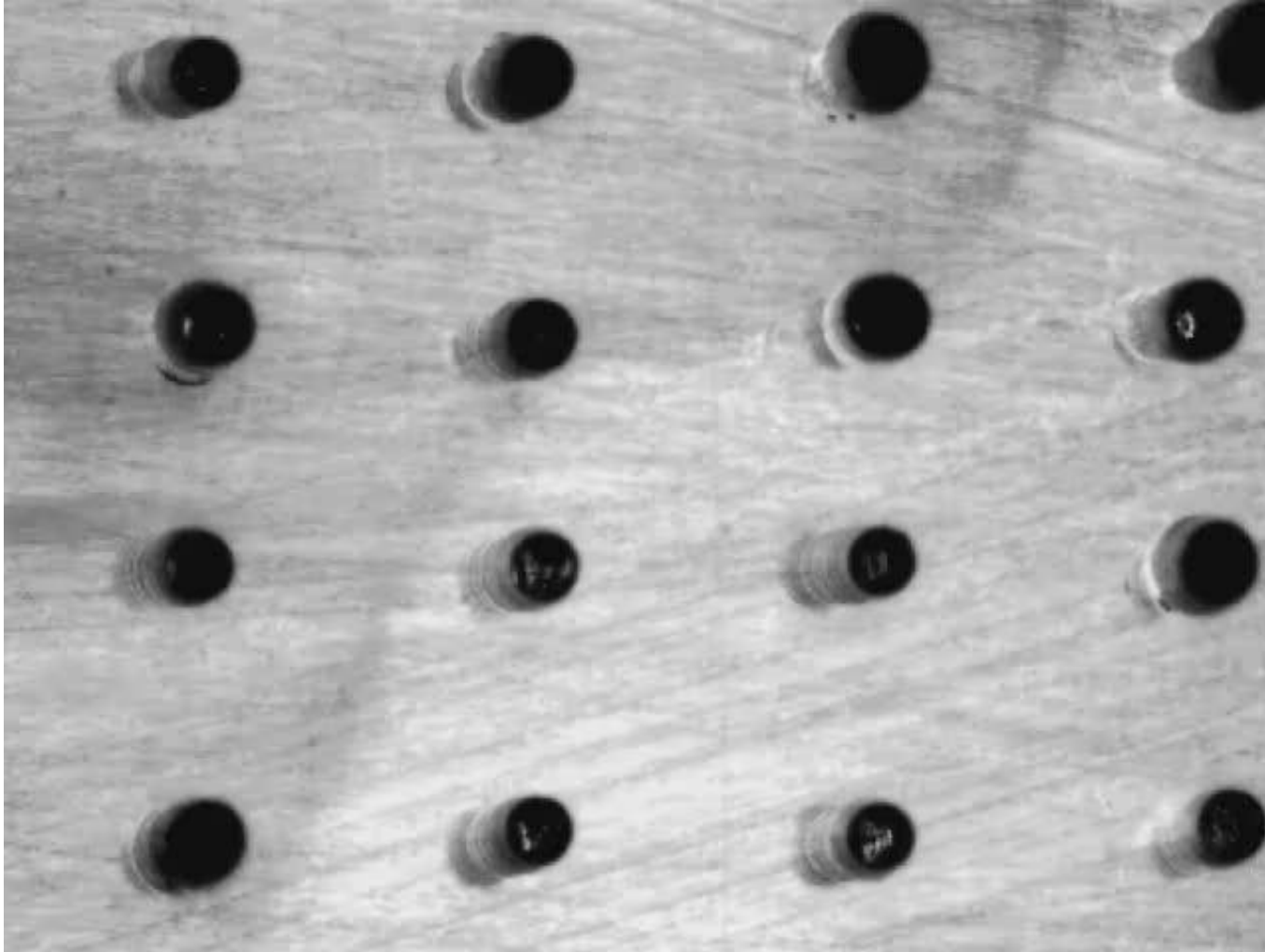


# Detailed structure

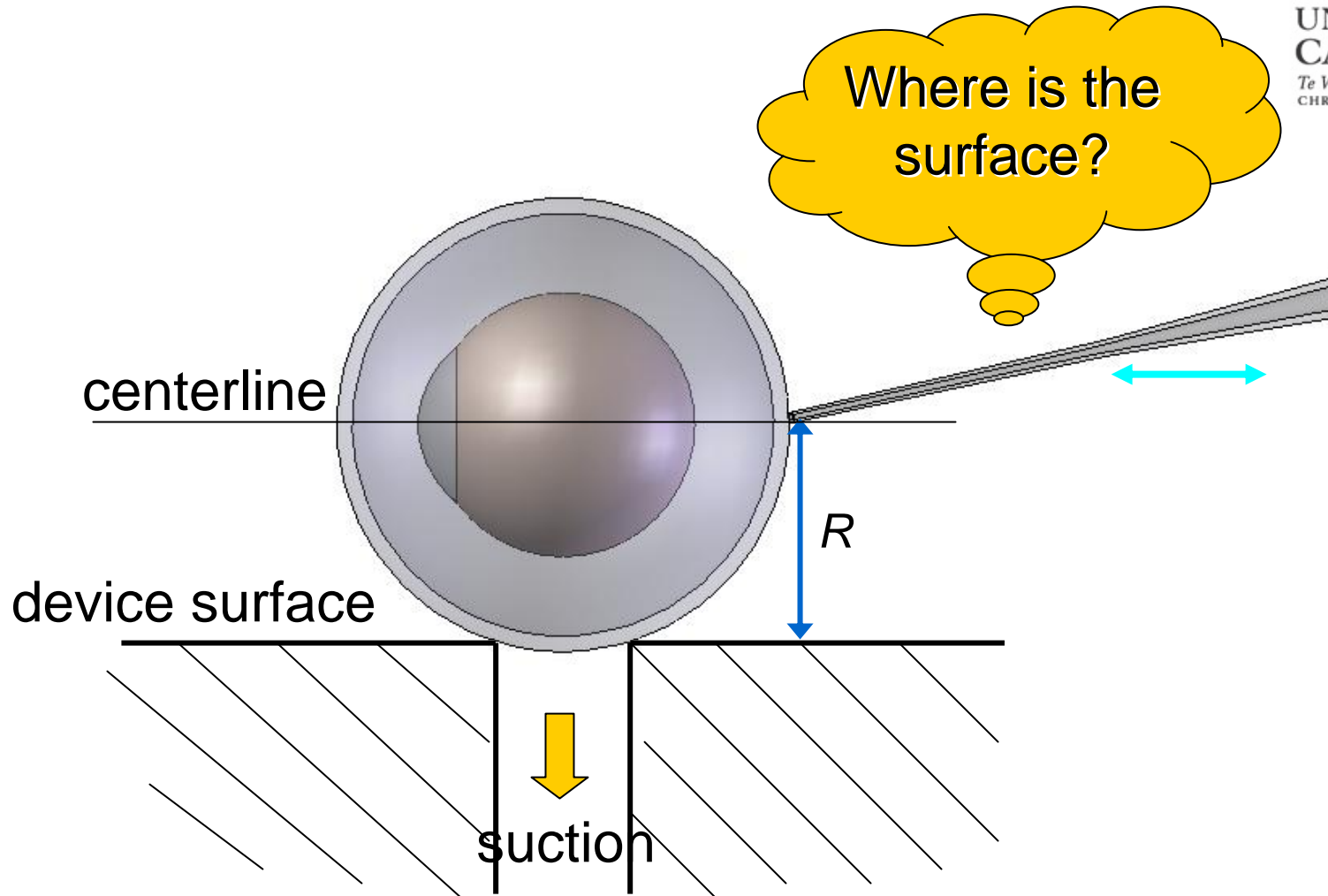




# Sample Preparation



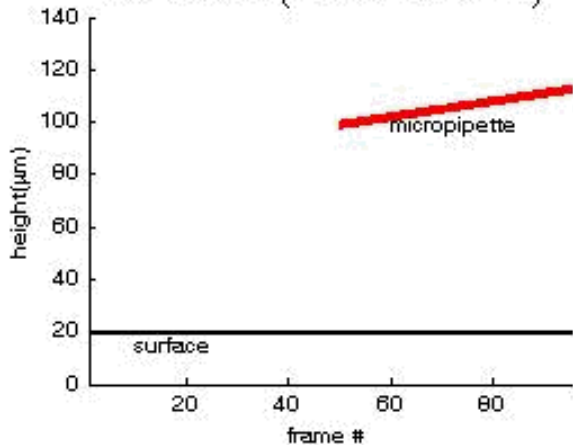
# Contact Detection



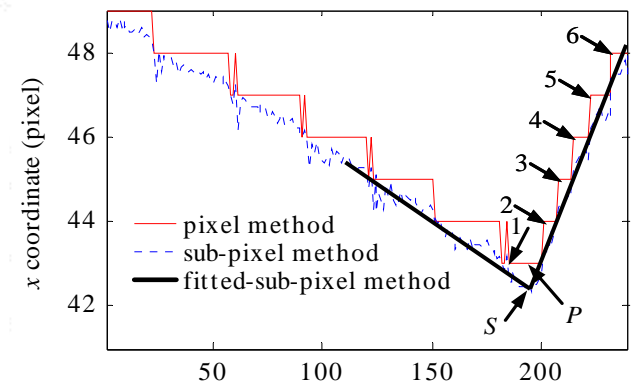
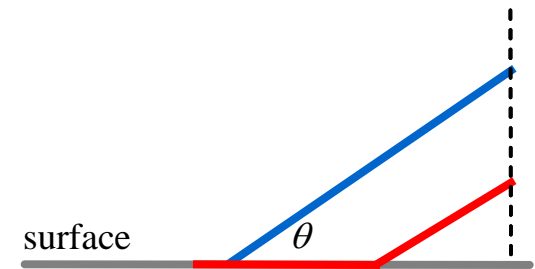
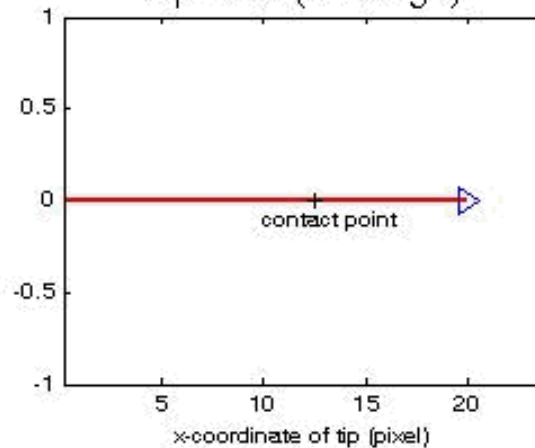
*Can we get 3D (Z) information from 2D (image plane x-y) information?*

# Contact Detection Principle

side view (in world frame)



top view (in image)



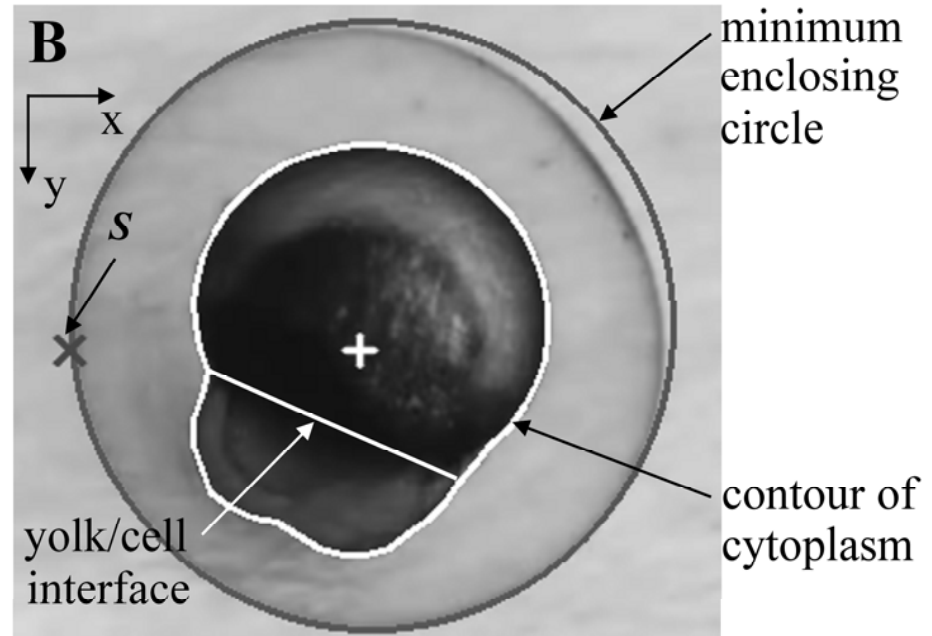
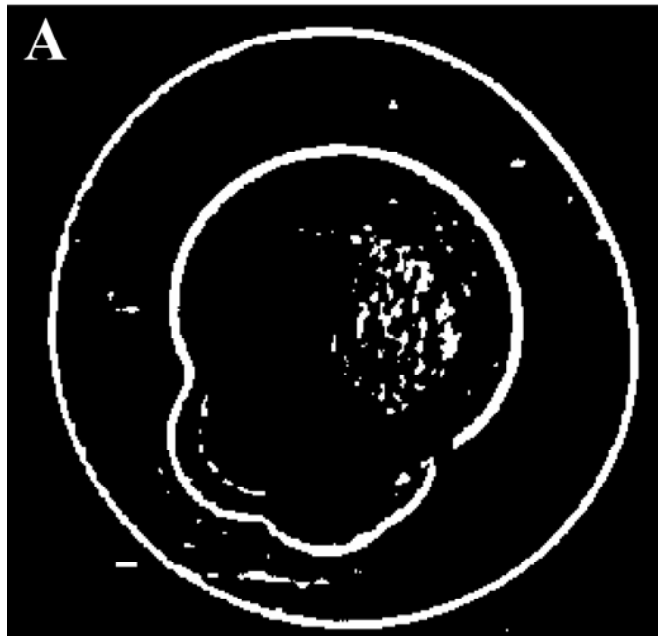
real case

contact detection procedure animation

*Int. J. Robot. Res.*, 26, 2007

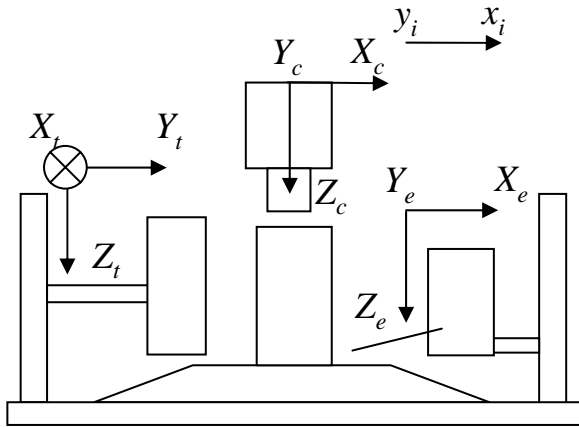
# Recognition of Embryo Structures

- Adaptive thresholding and morphological operations
- Snake tracking and convex deficiency calculations
- Recognition of chorion, cell, yolk, and cytoplasm center



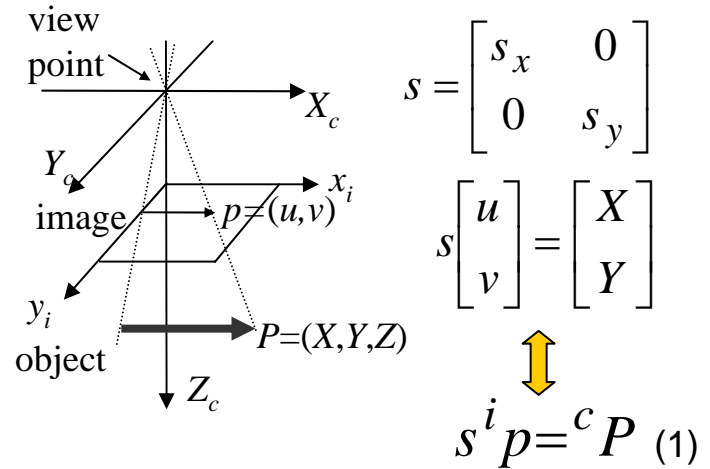


# Coordinate Frames & Transformation



$${}^e R_c = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$${}^t R_c = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$



microrobotic frames vs. camera frame

$${}^e P = {}^e R_c {}^c P + {}^e t_c$$

$${}^t P = {}^t R_c {}^c P + {}^t t_c$$



microrobotic frames vs. image frame

$${}^e P = {}^e R_c s^i p + {}^e t_c$$

$${}^t P = {}^t R_c s^i p + {}^t t_c$$

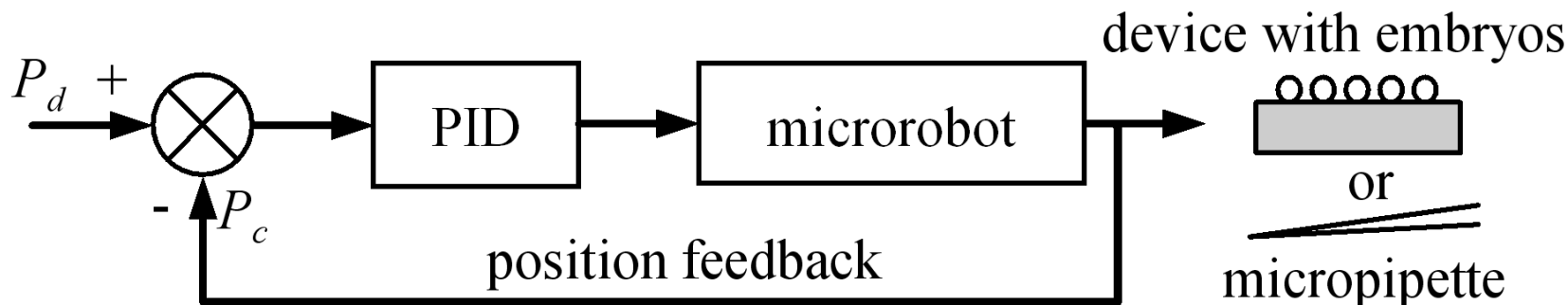
?

tip home position

initial cytoplasm centroid

# Looking-then-Moving

- Looking in image for initial positions of:
  - the tip
  - the deposition point
- Where to move in microrobotic frames?
  - coordinate frame transformation
- How to move?
  - position feedback from microrobots only



# Injection Control Sequence

contact  
detection → batch  
injection





# Force Pattern Characterization of *C. elegans* in Motion

- Introduction to *C. elegans*
- N Force Measurement Principle
- MEMS Fabrication Process
- Image Processing Algorithm
- Results

Image Source: PLoS Biol

Ali Ghanbari, Volker Nock, Wenhui Wang, Richard Blaikie, J. Geoffrey Chase, XiaoQi Chen, and Christopher E. Hann (2008). "Force Pattern Characterization of *C. elegans* in Motion", 15th Intl Conf on Mechatronics and Machine Vision in Practice (M2VIP), Auckland, New Zealand, Dec 2-4, CD-ROM.

# C. elegans – Locomotion

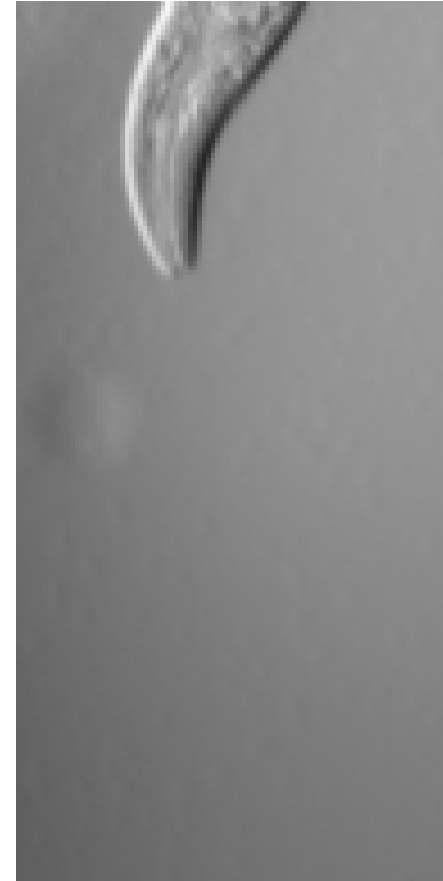
## *C(aenorhabditis) elegans*

- free-living nematode (roundworm)
- about 1 mm in length, 100µm in width
- lives in temperate soil environments
- used extensively as a model organism

*C. elegans* was the first multicellular organism to have its genome completely sequenced (1998)

### Challenging because:

- *C. Elegans* are very small:
  - **cannot use conventional force measurement techniques**
- *C. Elegans* are living organisms:
  - **non-intrusive measurement technique required**



# Cellular Force Modelling

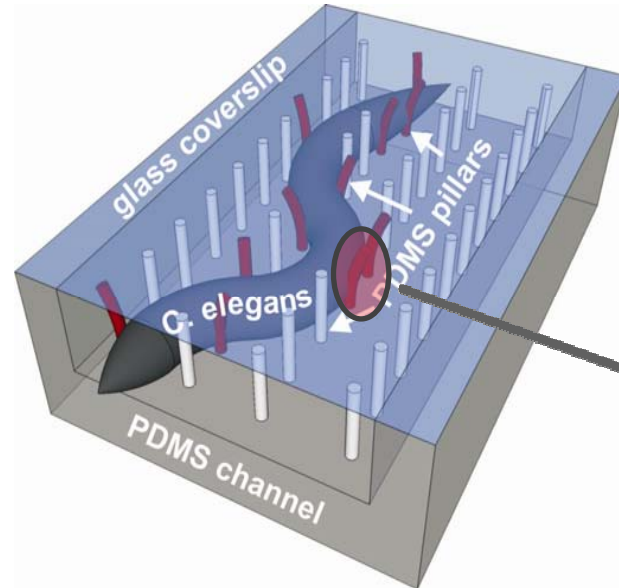
- At force point:  
Bending + Shear

$$\delta = \left( \frac{l^3}{3EI} + \frac{20(1+\gamma)l}{9AE} \right) \cdot f$$

- From force point to the  
free end of the pillar:  
Just Bending

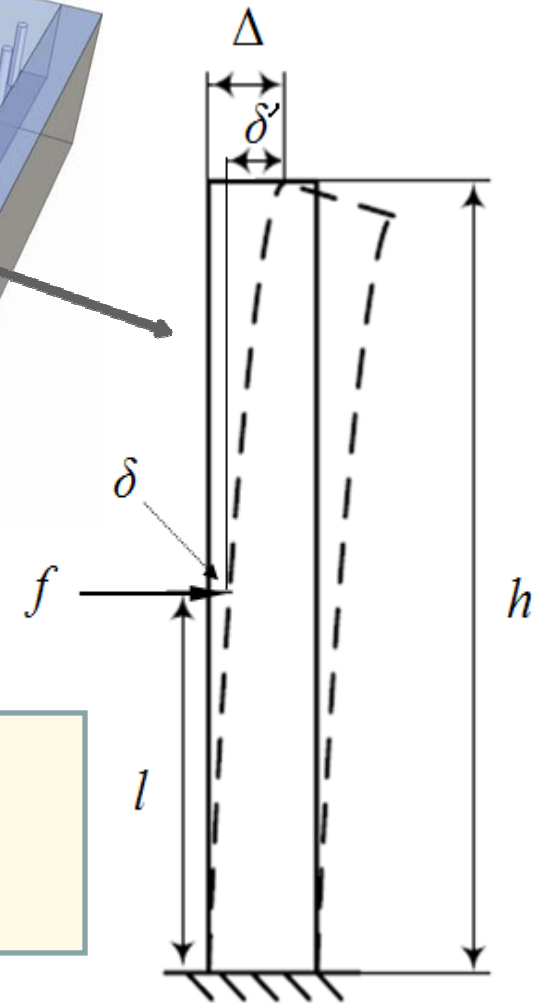
$$\delta' = \frac{l^2}{2EI} (h - l) \cdot f$$

$I$ : moment of inertia  
 $E$ : Young's modulus  
 $\gamma$ : Poisson's ratio



$$\Delta = \delta + \delta'$$

$$f = \frac{\Delta}{\left( \frac{l^3}{3EI} + \frac{20(1+\gamma)l}{9AE} \right) + \frac{l^2}{2EI}(h-l)}$$





# Detecting Pillar Deflection

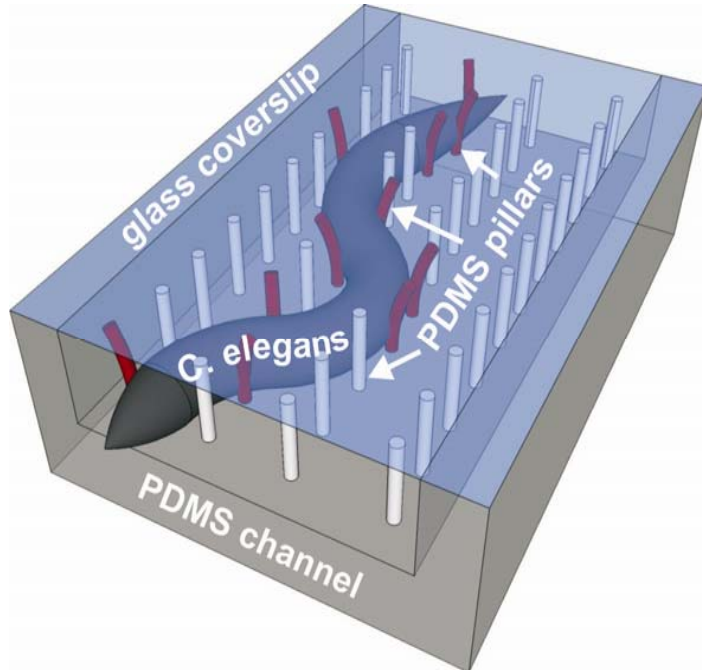
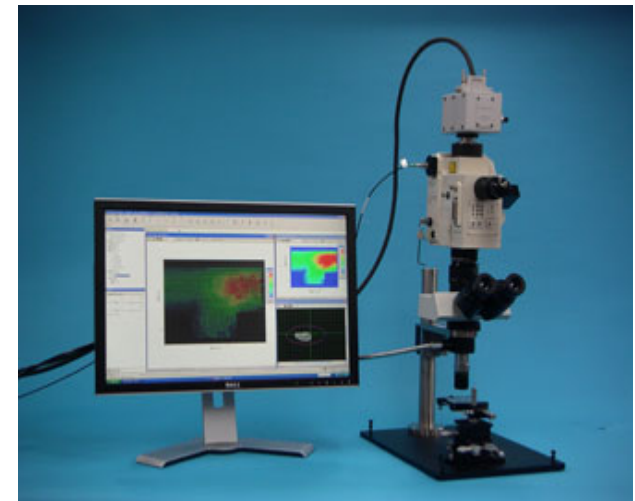


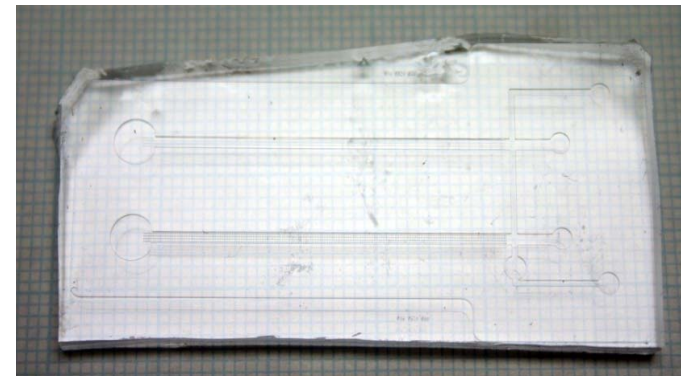
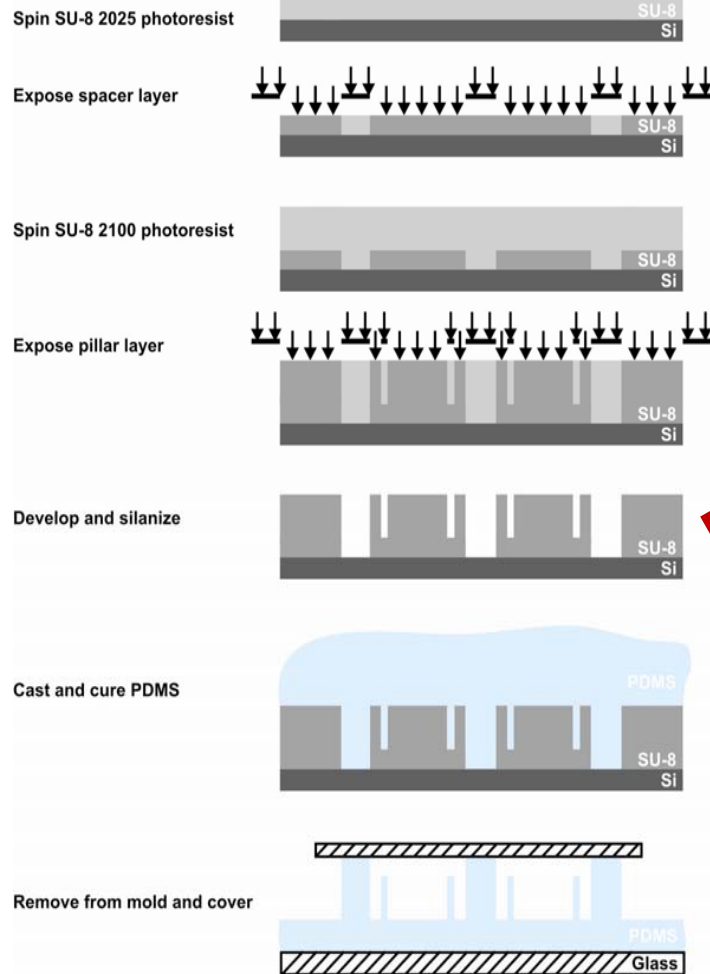
Image  
capture and  
processing  
setup

Parameters for Pillar Array:

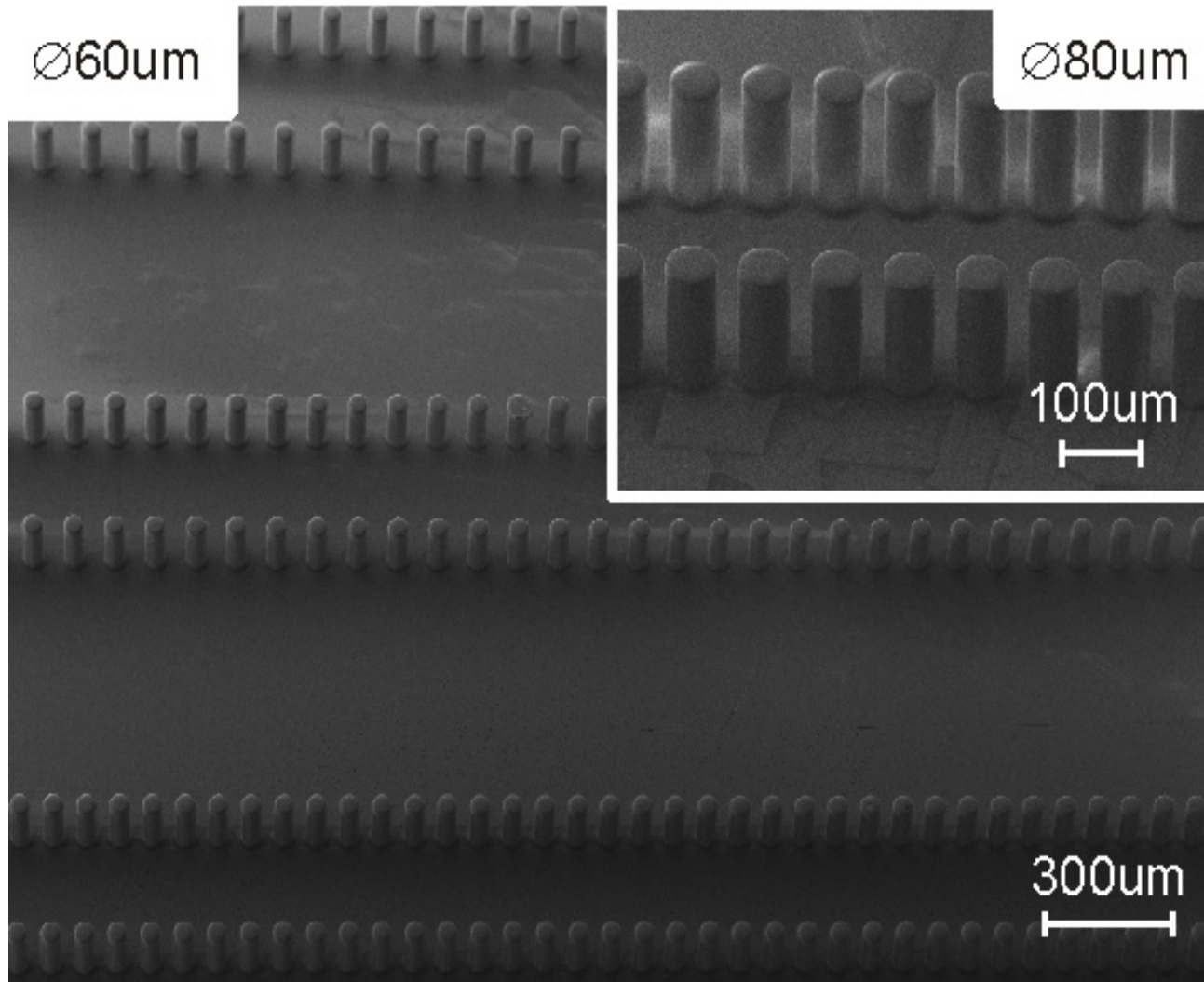
- stiffness of silicone
- pillar diameter
- spacing
- height



# MEMS Fabrication



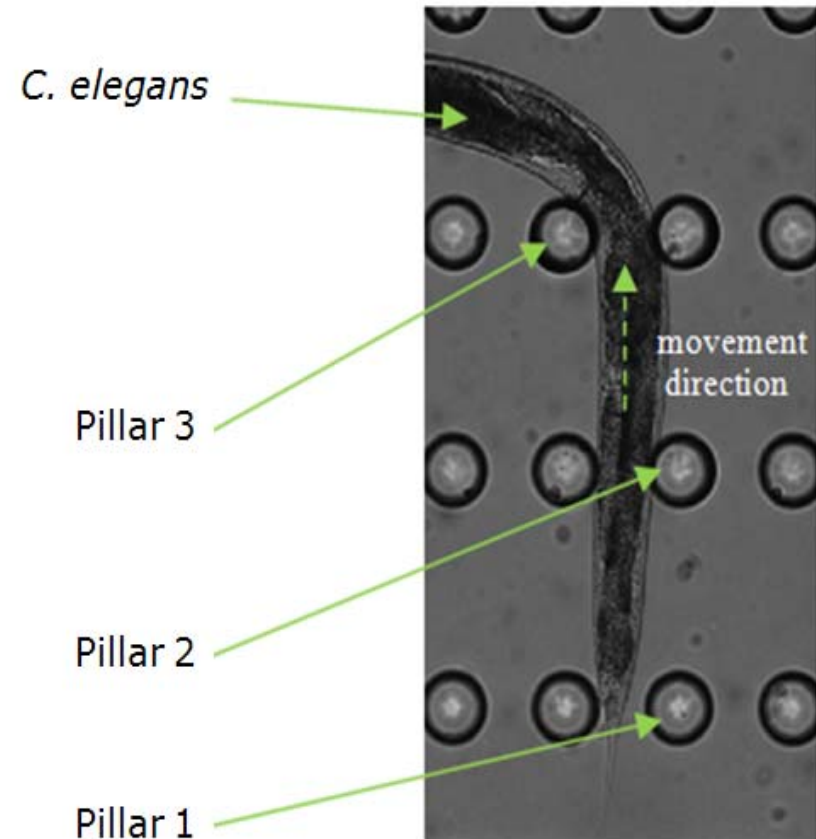
# Device Molds





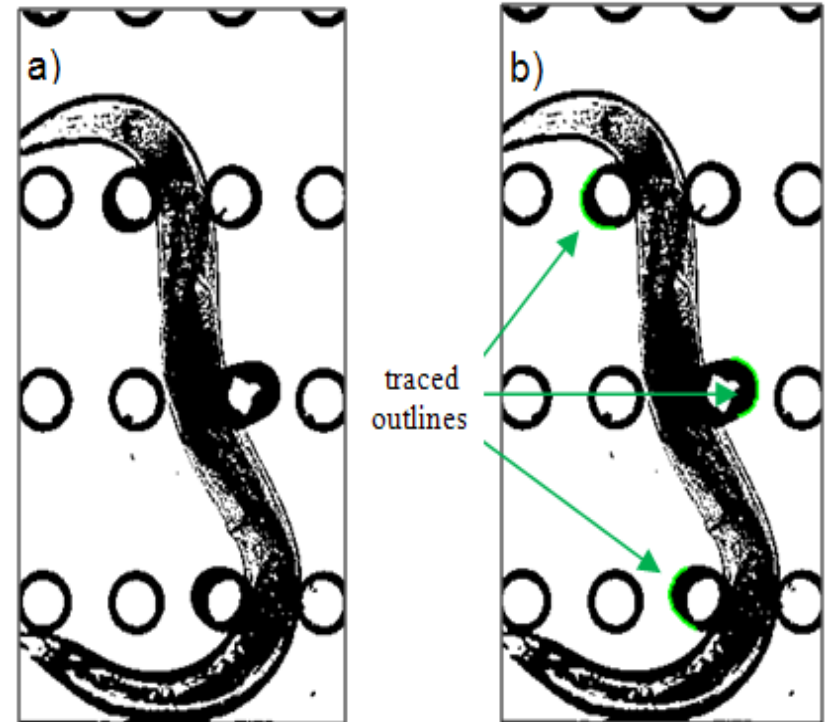
# Image processing

- Without loss of generality, three specific pillars targeted for image processing
- Frames converted to black and white to have binary images
- Three zones defined to extract each pillar image in an assigned square window
- A Boundary Tracing Algorithm developed and adapted to trace the outline of the outer circle of the deflected pillars



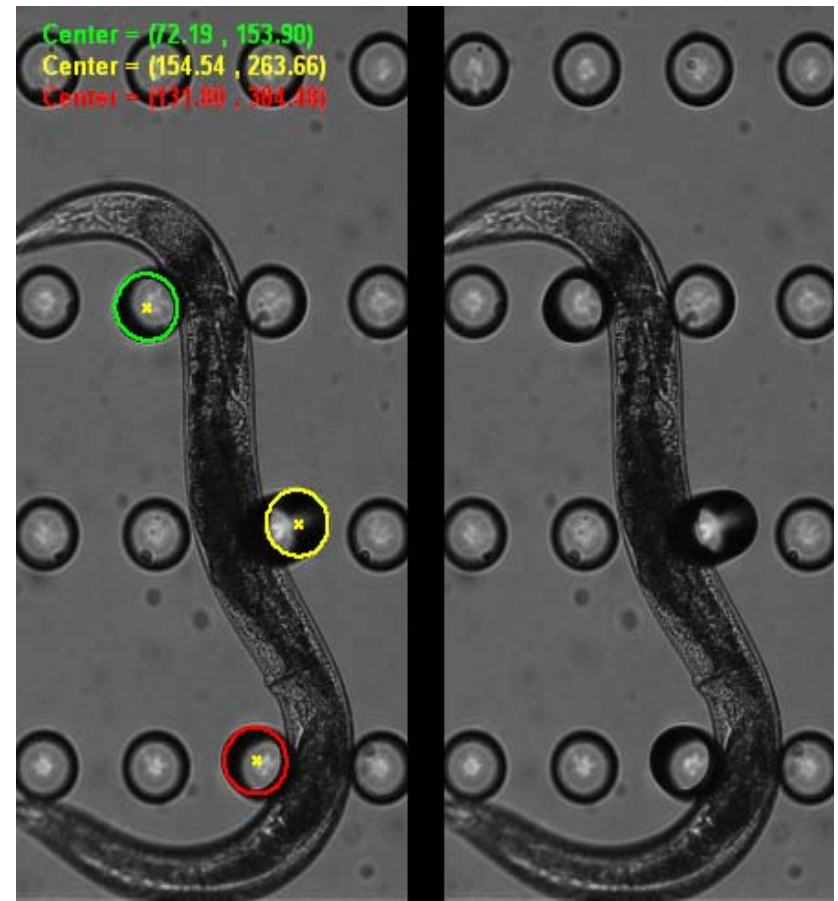
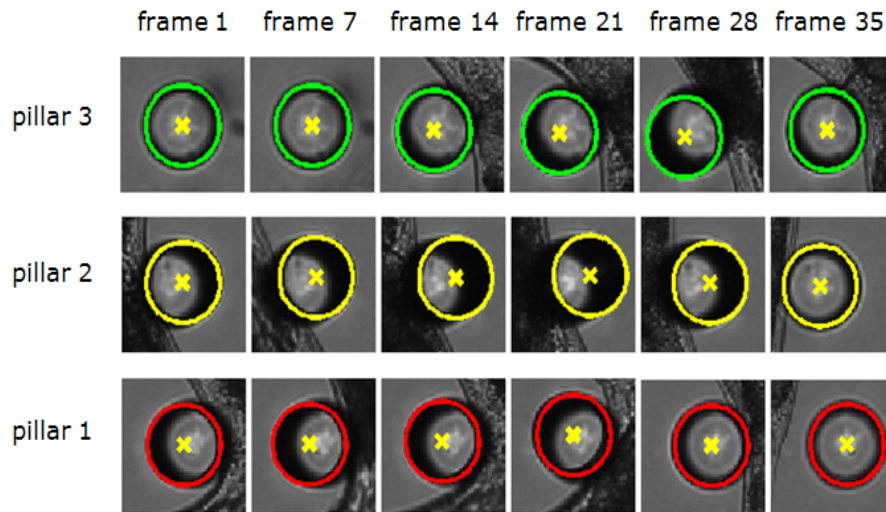
# Image processing Algorithm

- Scanning the square window from bottom left:  $P_0$
- Searching the  $3 \times 3$  neighborhood of the current pixel in an anti-clockwise direction.
- The circle point tracing is repeated up to detecting nth pixel  $P_n$ .

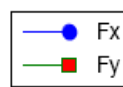
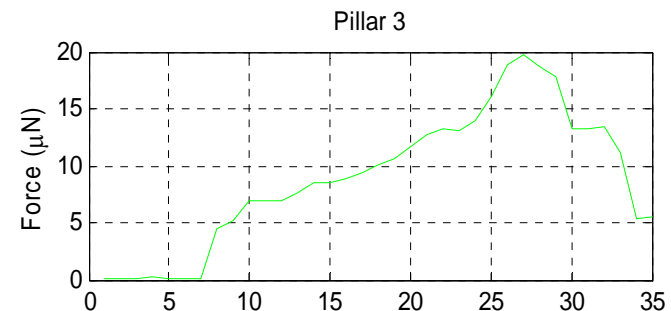
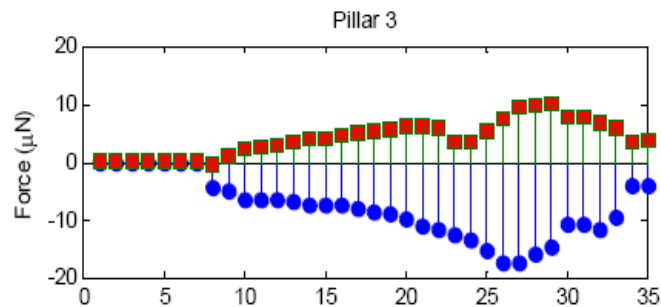
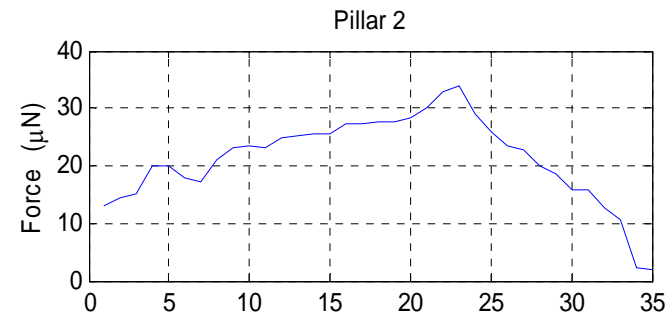
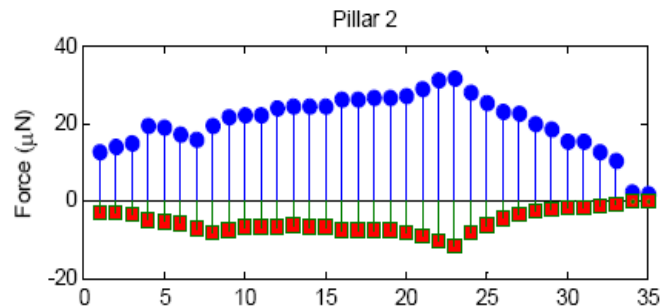
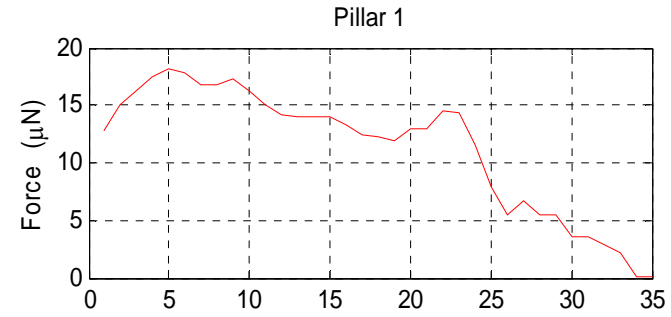
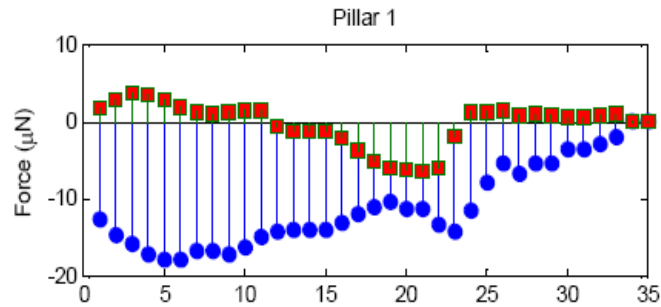


# Image processing Algorithm

- A least-square fitting algorithm was employed to fit a circle to the traced points



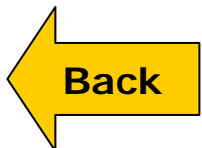
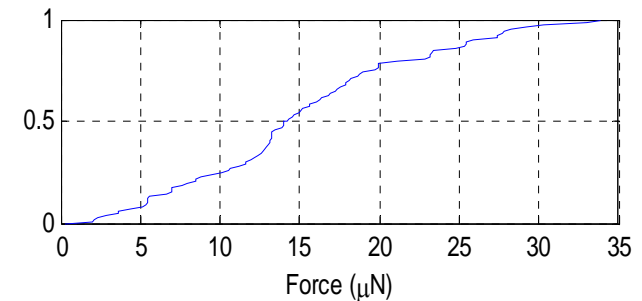
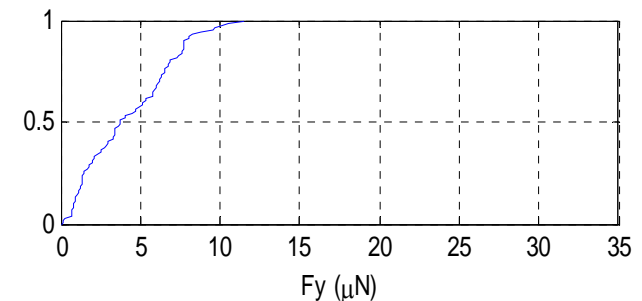
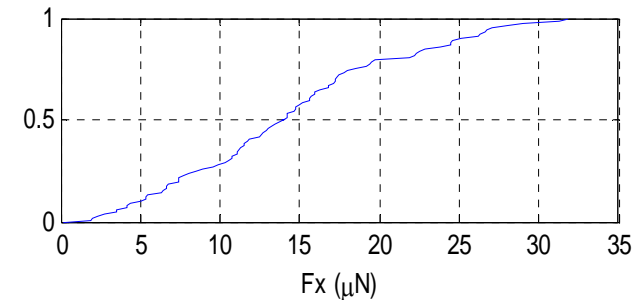
MAX FORCE	PILLAR 1	PILLAR 2	PILLAR 3
$ f_x $ ( $\mu\text{N}$ )	17.93	31.85	17.48
$ f_y $ ( $\mu\text{N}$ )	6.58	11.52	10.08
$ f $ ( $\mu\text{N}$ )	18.15	33.87	19.76





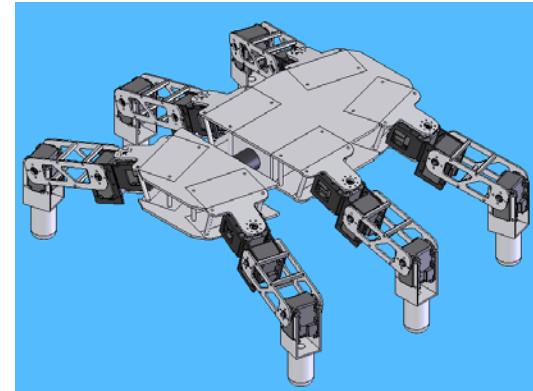
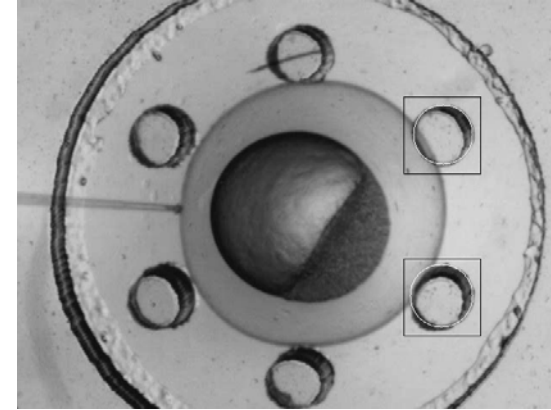
# Cumulative Distribution of Calculated Forces

- Sorting the all calculated forces of three pillars except zero ones from smallest to largest and distributing them between 0 to 1 with steps of one over the number of sorted forces.
- A nearly linear cumulative distribution function (CDF) will be obtained, which implies an approximately uniform distribution of forces.
- It shows a highly variable and continuous force level produced by the worm, which is in accordance with biological results and the anatomy of *C. elegans*.

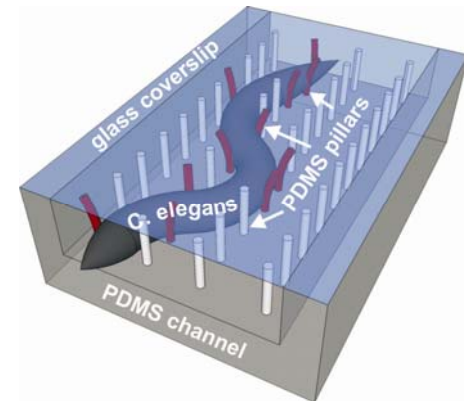
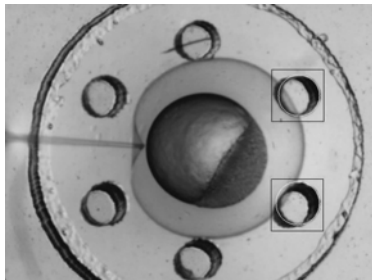
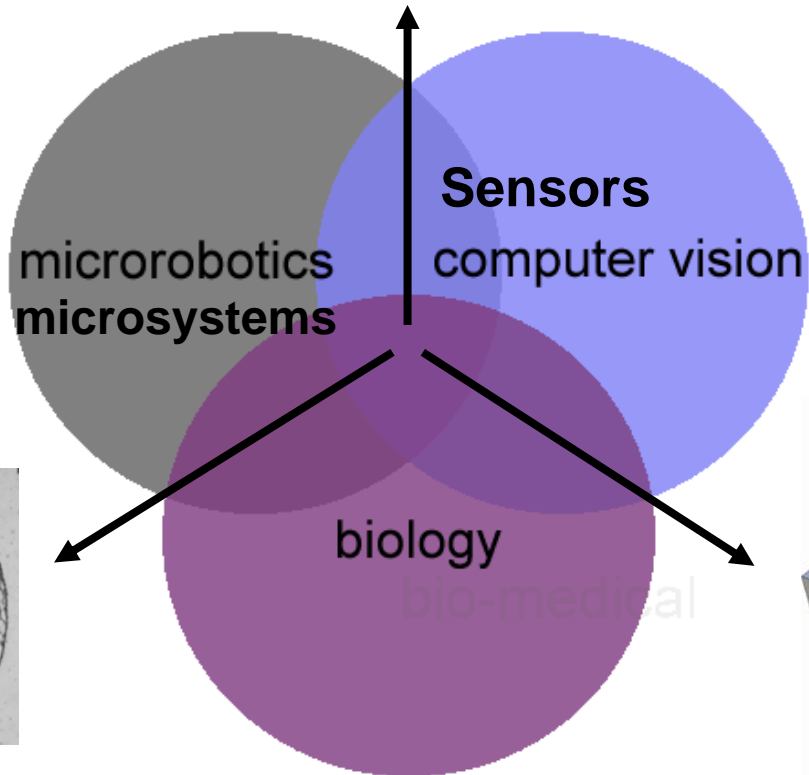
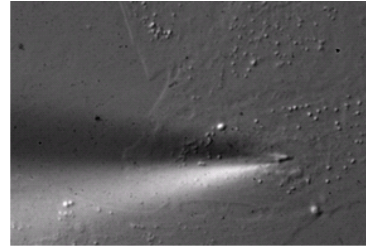
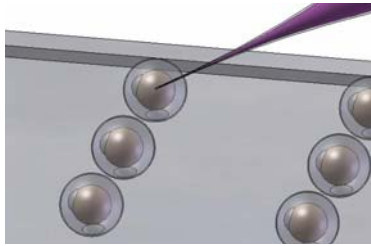


# Conclusion & Future Work

- Assistive robotic devices
  - Prosthetics, Rehabilitation
  - Active assistant
- Biologically inspired robots
  - Biomimetics study
  - Novel micro actuator and mobility control
  - Situational awareness (feeler, vision, tactile, sound)
- Human machine interface technology
  - Augmented reality
  - Haptics device for virtual presence and virtual training
  - Brain-computer interface
- Mobile robotics
  - Mobility: hybrid wall climbing mechanism (Bernoulli pad++), untethered
  - Sensing: vision for motion sensing in place of expensive IMU
  - Environmental / resource measurement, monitoring
  - Automating complex tasks in natural environment.
- Energy harvesting
  - Convert mechanical energy to electric power. Cost & efficiency.
  - Self-powered wireless instrument



# Biomechatronics



MERCI!  
THANK YOU!



*Questions ?*